A Neural Network Based Approach to Predict Solar Radiation and Analyze the Suitability of Crops Based on Atmospheric Conditions

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ABSTRACT- **Solar energy is one of the basic elements for all renewable and fossil fuels. Solar radiation data is always a necessary basis for the design of any solar energy conversion device and for a feasibility study of the possible use of solar energy in variety of applications. In the existing system the prediction of solar radiation is based on feed forward neural networks. The drawback behind that is they are less accurate. Hence the proposed system is used to predict solar radiation based on a non-linear autoregressive exogenous input model and find the suitability of crops for cultivation based on the atmospheric conditions. The daily average solar radiation for Tiruvallur region is predicted based on climatic factors such as minimum air temperature, maximum air temperature, air pressure and humidity that influence the crop yield for Tiruvallur region. A non-linear autoregressive exogenous input (NARX) is built to predict the solar radiation. The performance of the network is then analyzed by calculating the mean squared error and Regression analysis. The performance analysis is done to determine the accuracy between the actual data and predicted data. Based on the predicted solar radiation and along with other climatic parameters such as the amount of rainfall, soil, duration and suitable months the crops that are suitable for cultivation around Tiruvallur region are analyzed, identified and suggestions are provided to farmers. This work results in benefit of the farmer community around Tiruvallur region.**

I INTRODUCTION:

Solar radiation is the energy that the earth receives from sun which acts as a basis for all living species. Hence this solar radiation acts as the ultimate source for all physical and biological processes on earth. In the recent years the need for forecasting and predicting solar radiation has increased.

The intensity of solar radiation for a particular location is determined by various climatic parameters such as minimum air temperature, maximum air temperature, air pressure, relative humidity, wind speed, wind direction and so on. These climatic parameters are essential and important for the prediction of solar radiation for various geographic locations.

Many studies were made and others are still conducted in order to design and build such prediction systems. Some of them are as follows,

Ji Wu, Chee Keong Chan, Yu Zhang, Bin Yu Xiong, Qing Hai Zhang(2013), proposed a genetic approach combining multi-model framework(GAMMF) for solar radiation time series prediction. The framework was started with the assumption that there exist several different patterns in the stochastic component such as different seasons,weather conditions and other factors of the solar radiation series. To uncover the pattern, genetic algorithms was used to segment the solar series, and are grouped into different clusters. Genetic algorithm was used to find the optimal segment of the solar radiation series. For each cluster, a prediction model was trained to represent the specific pattern. In the prediction phase, identifying the pattern was of great importance. Thus a procedure for the pattern identification was performed to identify the proper pattern for the series it belonged to. The prediction result of the proposed framework was then compared with algorithms such as Autoregressive moving and average model(ARMA) and Time delay neural

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networks(TDNN).The comparitive results showed that the proposed framework provided better performance than other algorithms[19].

Jianping Wang, Yunlin Xie, Chenghui Zhu, Xiaobing Xua(2011) used the wavelet analysis and neural network to establish the solar radiation wavelet neural network model. The model was trained with phase space reconstruction solar radiation data. Using wavelet neural network the solar radiation was predicted to solve the nonlinear and non-stationary problem. The nonlinear process of solar radiation was forecasted by neural network and the non-stationary process of solar radiation was decomposed at different frequency scales by multi-scale characteristics of wavelet transform. The model was trained with temperature, clearness index, and phase space reconstruction radiation data. After trained with those data it was able to predict solar radiation energy well. The phase space reconstruction data was used to train the wavelet neural network to determine dimension and delay time to improve the prediction accuracy and it consumes less time[20].

Khan, M.A.; Huque, S. ; Mohammad, A. (2013), focused on the development of artificial neural network (ANN) model for estimation of daily global solar radiation on horizontal surface. In this analysis back-propagation algorithm was applied. Day of the year, daily mean air temperature, relative humidity and sunshine duration were used as input data. The database consisted of daily measured data, collected for four years, in terms of daily mean air temperature, relative humidity, sunshine duration and global solar radiation. MATLAB neural network toolbox was used to train and test the network. Both the estimated and measured values of daily global solar radiation on horizontal surface were compared during testing phase statistically using two methods: Root Mean Square Error (RMSE) and Regression R Value (R), giving a value of 113.6 Wh/m^2 and 0.9744, respectively. The results of this study showed a better accuracy than other conventional prediction models that have been used[2].

Smart grid initiatives are significantly increasing the fraction of grid energy contributed by renewable. One challenge with integrating renewable into the grid is that their power generation is intermittent and uncontrollable. Thus, predicting future renewable generation is important, since the grid must dispatch generators to satisfy demand as generation varies. While manually developing sophisticated prediction models may be feasible for large-scale solar farms,but developing them for distributed generation at millions of homes throughout the grid is a challenging problem. To address this problem, **Sharma P. Irwin, D. ; Shenoy, P(2011),**proposed automatically creating site-specific prediction models for solar power generation from National Weather Service (NWS) weather forecasts using machine learning techniques. They compared multiple regression techniques for generating prediction models, including linear least squares and support vector machines using multiple kernel functions. They evaluated the accuracy of each model using historical NWS forecasts and solar intensity readings from a weather station deployment for nearly a year. Their results showed that SVM-based prediction models built using seven distinct weather forecast metrics are 27% more accurate for their site than existing forecast-based models[21].

This paper presents the experimental works on designing, implementing and validating the approach to predict solar radiation using various climatic parameters through non-linear autoregressive with exogenous input model. This type of neural network is appropriate to time series prediction. This paper shows the advantage of NARX model over feed-forward networks.

II NON-LINEAR AUTO REGRESSIVE NETWORK WITH EXOGENOUS INPUTS(NARX):

Neural network is an interesting tool for both linear and non-linear systems. The nonlinear autoregressive network with exogenous inputs (NARX) is a recurrent dynamic network, with feedback connections enclosing several layers of the network. The NARX model is based on the linear ARX model, which is commonly used in time-series modeling.

The defining equation for the NARX model is

$$y(t)=f(y(t-1),y(t-2),\ldots,y(t-n_y),u(t-1),u(t-2),\ldots,u(t-n_u)) \quad (1)$$

where the next value of the dependent output signal $y(t)$ is regressed on previous values of the output signal and previous values of an independent (exogenous) input signal. NARX model can be implemented by using a feed forward neural network to approximate the function f. A diagram of the resulting network is shown below,

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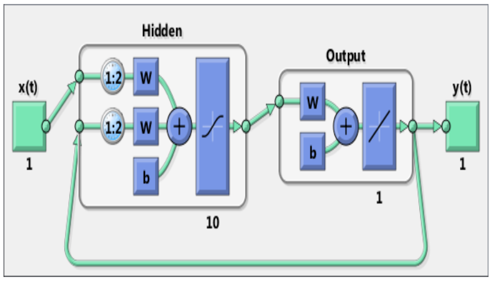

Figure 1: NARX model with feedback connections

III FEED FORWARD AND NARX BASED SOLAR RADIATION PREDICTION:

The feed forward network acts as the reference system to the NARX system that is developed. The proposed system is implemented using MATLAB software. In the design and validation phases the meteorological database collected from the NASA surface meteorology is used for prediction. Each daily record includes the following meteorological parameters: minimum air temperature, maximum air temperature, air pressure, relative humidity.

The collected data is then divided in to two subsets. The design subset is used to design and train the neural networks while the test subset is used to validate the trained network. The data is preprocessed and normalized within the network that is being created.

Initially, the feed forward reference system is created to predict solar radiation. The core component of this system is composed of three layers: an input layer, hidden layer and output layer. The input layer consists of the parameters, the information from the input layer is then processed to the hidden layer, and the output vector is computed in the final output layer.

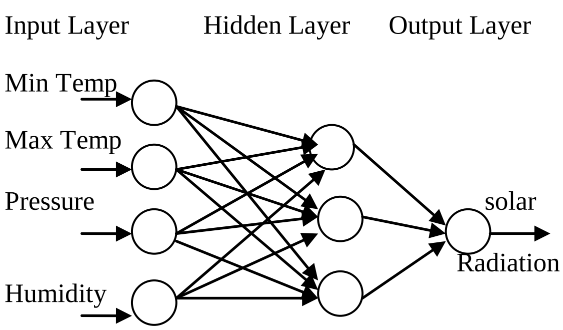

Figure 2: Feed Forward Network

In the proposed system the NARX model is created and trained that included: an input layer with four inputs, a hidden layer, an output layer of one node outputs the estimated solar radiation. The feedback connections were made to feed the hidden layer by the output of the network for a previous input.

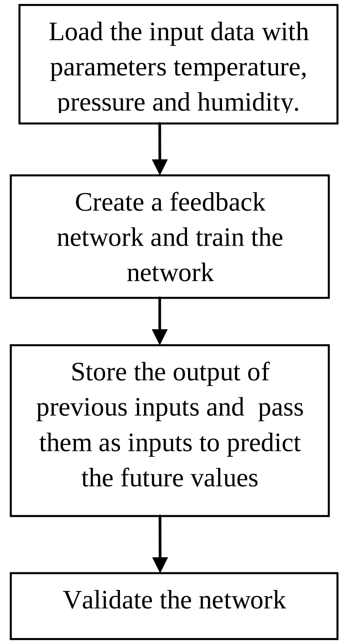

Figure 3: Steps involved in NARX

Both the networks are trained by using Back- Propagation algorithm which is used to initialize weights and biases between the network layers. This algorithm helps in propagating the error backward from output nodes to the input nodes to calculate the error by modifying the weights[18].

V CROP ANALYSIS

Crop communities exert a strong influence on local environments. Crops are prone to all local and physical changes that occurs in the environment. One of the most important factors that influences plants development is the solar radiation intercepted by the crop. The solar radiation brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation that makes synthesize vegetal components from water, CO_2 and the light energy possible. A part of this, energy is used in the evaporation process inside the different organs of the plants, and also in the transpiration through the stomas. Hence the global solar radiation acts as a key input variable for crop cultivation.

This paper identifies the suitable crops that can be cultivated around Tiruvallur region. The parameters that are taken in to consideration are

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Table 1 Suitable crops for cultivation around Tiruvallur region

crop	Temperature(degree celcius)	Rainfall(cm)	soil	Duration(days)	Suitable months
Ash gourd	22-35	warm	Deep loamy	140-150	March-June
Bitter Gourd	30-35	Warm, dry climate	Loamy	60-70	May-July
Brinjal	20-30	10-20	Sandy loam	120-130	December-February
Cauliflower	23-28	Avoid rainy seasons	Sandy loam and clayey loam		September-November
Chilly	20-30	70-100	Sandy-heavy clay	40-45	June - October
Rice	20-40	15-20	Sandy	90-110	October-April
Tomato	18-25	warm	Sandy loam	90-150	January-May

V EXPERIMENT AND RESULTS:

The performances of the two approaches are studied by comparing the statistical analysis. The statistical analysis is performed by computing the Mean squared error and regression analysis. The Mean Squared Error (MSE) indicates the square of the average deviation of the estimated values from the corresponding target data. The lower MSE is desirable. A positive MSE value indicates the amount of over estimation in predicted values and vice versa. The regression analysis is used to understand the accuracy between the actual value and the predicted value. The Mean Squared error is computed by the following equation,

$$\text{MSE}=\frac{1}{N}\sum_{i=1}^{N}\left(H_p - H_i\right)^2 \qquad [2]$$

Where H_p represents the estimated value of solar radiation, H_i is the measured value of the solar radiation and N represents the total number of observations[22].

The data measured for five years are used for training, testing and validation. Once the neural network is trained i.e., all the weights and biases are set, the network can be tested. The network is trained by seven back-propagation training algorithms: Levenberg-Marquardt(trainlm), Resilient BackPropagation (trainrp), Scaled Conjugate

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Gradient (trainscg), Conjugate Gradient with Powell/Beale Restarts(traincgb), Fletcher-Powell Conjugate Gradient (traincgf), Polak-Ribiere Conjugate Gradient (traincgp), and one step Secant (trainoss). The validation checks at each epoch results produced by the seven training algorithms based feed forward network and NARX network are shown below,

Table 2 MSE and Regression Analysis of Feed-Forward Network

Training Algorithms	Epochs	MSE	Regression Analysis
trainlm	9	4.05	0.28
trainrp	91	4.8	0.27
trainscg	21	6.01	0.25
traincgb	26	3.8	0.28
traincgf	15	5.68	0.26
traincgp	18	4.27	0.25
trainoss	14	6	0.16

Table 3 MSE and Regression Analysis of NARX Network

Training Algorithms	Epochs	MSE	Regression Analysis
trainlm	14	1.8	0.78
trainrp	58	1.9	0.76
trainscg	24	1.8	0.75
traincgb	22	1.5	0.75
traincgf	29	1.9	0.76
traincgp	16	1.6	0.73
trainoss	14	2.16	0.73

The above table shows that the NARX network trained with Levenberg-Marquardt algorithm converges faster than other algorithms. Where the training stopped after 14 epochs. The Mean Squared error of the training period was found to be 1.8 and the regression analysis after training, validation and testing is found to be 0.78. The Narx model shows quite closer results of the scatter plot during training, validation and testing of the experimental data. Figure (3) and (4) shows the comparison results of feed forward network and NARX network in terms of performance and Regression analysis.

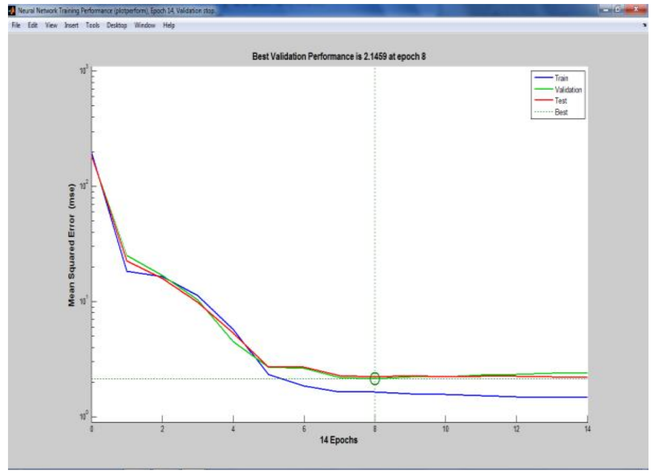

Figure 4: Performance Graph of NARX

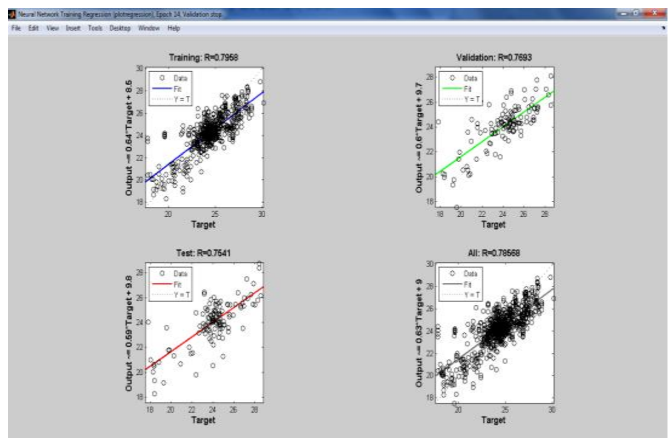

Figure 5: Regression Analysis of NARX

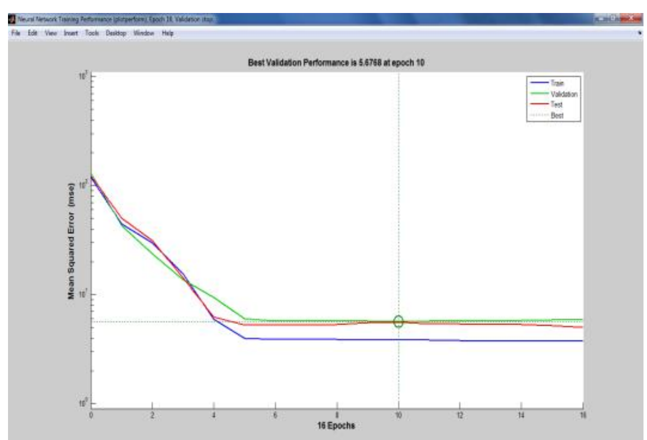

Figure 6: Performance Graph of Feed Forward Technique

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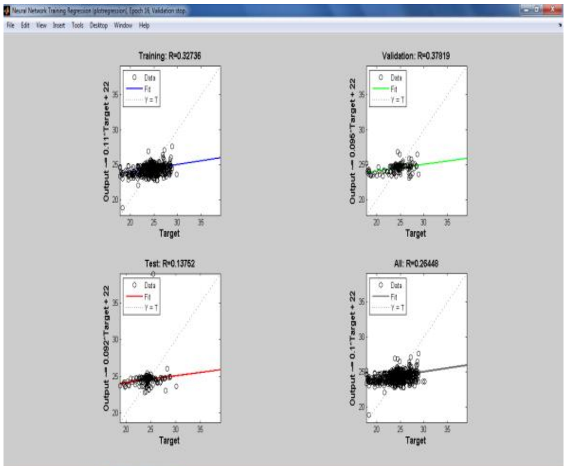

Figure 7: Regression Analysis of Feed Forward Technique.

CONCLUSION:

In this study, an approach to estimating solar radiation from meteorological data sets based on feed forward and NARX model using different training algorithms has been developed. The comparative analysis between the estimated data and measured data showed that NARX model has the ability to recognize the relationship between the input and output variables and predict solar radiation accurately. The statistical error analysis shows the prediction accuracy. The Marquardt-Levenberg learning algorithm of NARX mode produces a minimum mean squared error and maximum coefficient of determination i.e., regression value, in both training and validation of data sets. Hence NARX model produces more accurate results than the feed forward technique.

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